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Site Characterization, Design, and Construction for Closure of Four Hazardous Waste Landfills at a Superfund Site

Anirban De
Manhattan College, Riverdale, New York

R. Jeffrey Dunn
Kleinfelder, Inc., Pleasanton, California,

Neven Matasovic
GeoSyntec Consultants, Huntington Beach, California

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SITE CHARACTERIZATION, DESIGN, AND CONSTRUCTION FOR CLOSURE OF FOUR HAZARDOUS WASTE LANDFILLS AT A SUPERFUND SITE

Anirban De
Department of Civil Engineering
Manhattan College
Riverdale, New York, U.S.A.

R. Jeffrey Dunn
Kleinfelder, Inc.
Pleasanton, California, U.S.A.

Neven Matasovic
GeoSyntec Consultants
Huntington Beach, California, U.S.A.

ABSTRACT

Various elements related to extensive geotechnical and seismic site characterization, design, and construction for the closure of four hazardous waste landfills and their interstitial areas at a major federal Superfund site are discussed. A major challenge was the geotechnical characterization of bulk and containerized hazardous waste for the purpose of stability analyses. Design constraints included a highly seismic environment and a large design precipitation event. Design was completed in two separate phases, such that the closure design of three of the landfills was performed during and after the construction of the first. This allowed for lessons learned from the construction phase of the first landfill closure to be incorporated into the design of the final three.

INTRODUCTION

Background

The four hazardous waste landfills described in this paper are located at a closed hazardous waste disposal facility in the Central Coast region of California which is currently listed on the National Priorities List as a Federal Superfund site. The landfills were constructed directly within existing canyons and liners and/or or leachate collection systems were not constructed beneath the landfills. A site map showing the locations of the landfills in plan view is presented in Fig. 1. Weathered and unweathered claystones, which form the native bedrock in the area, provided limited containment on the excavated base and side-slopes of the landfills. The landfills received bulk and containerized wastes during the period from 1979 to 1989.

After 1989 closure activities were initiated and sludge material removed from on-site ponds and pads was stabilized, mixed with on-site soil, and placed over the landfills. This pond-bottom material placed over the landfills was up to 40 ft (12 m) thick and is referred to in the paper as "existing cap material". No other cover had been constructed on the landfills. The total thickness of waste material and existing cap material were up to as much as 150 ft (50 m).

The site characterization, design, and construction efforts described in this paper were part of closure activities, whereby engineered cover systems, approved for waste containment in hazardous waste landfills, was designed and placed on the four landfills. This work was conducted following a Consent Decree under oversight of the United States Environmental Protection Agency (USEPA), with the involvement of various environmental protection agencies of the State of California (California State EPA), and local authorities.

Scope

Site characterization was initially conducted on five (5) hazardous waste landfills on the site. The final characterization, design and construction were completed for final caps over four (4) of the landfills, as follows: Pesticides/Solvents (P/S), Heavy Metals/Sludges (M/S), Caustics/Cyanides (C/C), and Acids Landfills. The fifth landfill (PCB Landfill) was scheduled to receive a final cap at a later date.

SITE CHARACTERIZATION

Objective

The site characterization was conducted to evaluate the characteristics of the following elements:

a) General site and subgrade conditions
b) Existing cap material
c) Landfill waste mass
d) Existing toe buttress

This characterization was necessary for engineering design analyses, environmental assessment, and for ensuring compatibility of the final cap system with the existing cap material and the waste material.

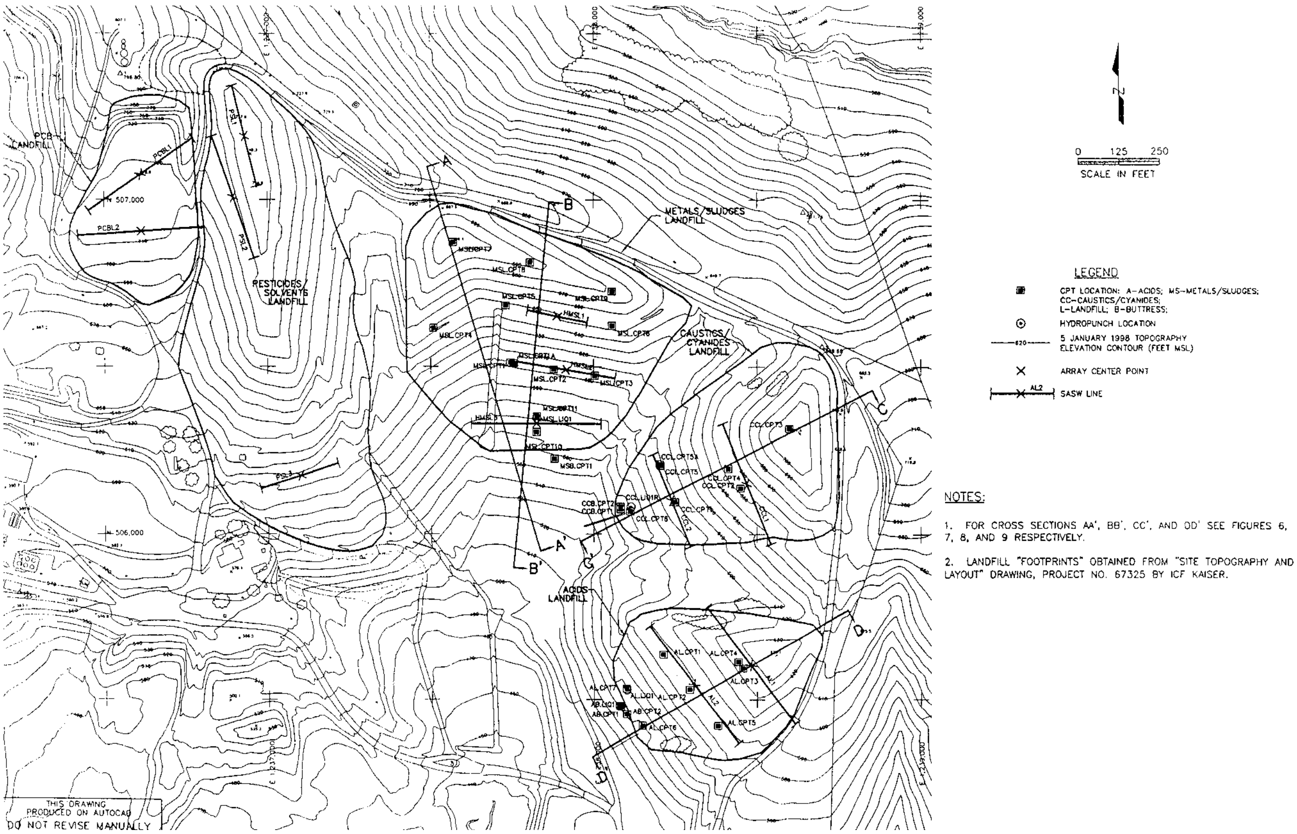


Fig. 1. Plan View of the Site, Showing the Locations of the Landfills and CPT and SASW Investigations

The site characterization process was challenging for several reasons. Minimal geotechnical data were available for the existing material and also very little technical guidance was available in literature regarding characterization of hazardous waste for geotechnical analyses. Further, any type of intrusive investigation was considered undesirable and difficult because of the potential for exposure to hazardous waste of largely unknown character and the consequent problem of disposal of cuttings and other exposed waste.

Components of Site Characterization

Site characterization for this project included the following components:

a) Site-specific seismic hazard evaluation and characterization of site geology
b) Geotechnical and environmental characterization of the existing cap material using
   i. Test pits
   ii. Gas flux measurements
   iii. Hollow-stem auger drilling (one landfill only)
   iv. Ground penetrating radar (GPR) (one landfill only)
   v. Cone penetration test (CPT) sounding
c) Geotechnical characterization of waste mass in the landfill
   i. Cone penetration test (CPT) sounding
d) Geotechnical characterization of the existing toe buttress
   i. Cone penetration test (CPT) sounding
e) Geophysical characterization of the landfills
   i. Spectral analyses of surface waves (SASW)

Several of the components listed above are described in further details in the following sections.

Site-specific Seismic Hazard Evaluation

The seismic hazard evaluation for this project was based upon the results of the seismotectonic investigation for a nuclear power plant in the relative vicinity of the site, and the site conditions and site-to-source distances specifically evaluated for the site. The design basis earthquake was a Maximum Credible Earthquake (MCE) defined as "the maximum earthquake that appears credible of occurring under the presently known geologic framework." The results of seismic hazard evaluation indicated that MCE for the site is moment magnitude, $M_w = 6.6$ on a thrust fault underlying the site at a distance of 2.6 km. The corresponding bedrock peak horizontal ground acceleration (PHGA) and the significant duration of strong shaking equal 0.86 g and 10 s, respectively.

Geotechnical and Environmental Characterization of the Existing Cap Material and the Waste Material

As part of the site characterization process, geotechnical and environmental properties of the existing cap material and the waste material were evaluated. The geotechnical properties included classification, index properties, undrained shear strength, and hydraulic conductivity. These properties were necessary for engineering design analyses such as slope stability analyses, settlement analyses and infiltration analyses (for the final cover system). Gas flux tests were completed to assess gaseous emissions from the landfills. Environmental samples were tested for metals, volatile and semi-volatile organic compounds (VOCs and SVOCs), polychloronated byphenols (PCBs), pesticides, and total recoverable petroleum hydrocarbons. These tests were done in order to evaluate the characteristics of existing cap materials that might be encountered and, possibly, excavated during the construction activities. It was also necessary to evaluate the compatibility of the liner material proposed for use in the final cover system with the chemicals in the existing cap material.

The following subsections provide further details regarding the field investigations into the existing cap materials.

Test Pits. Most of the excavations into the existing cap material were limited to the top 5 ft (1.5 m) depth. Therefore, test pits were the primary field investigation method. Test pits were excavated in a grid pattern to evaluate the geotechnical and environmental properties of the existing cap material. The test pits on the P/S Landfill were located at a spacing of 100 ft (30.5 m), while those on all the other landfills were located at a spacing of 200 ft (61 m). Each test pit was excavated to a total depth of 5 ft (1.5 m). A total of 101 test pits were excavated into the four landfills.

In each test pit, measurements of in-situ density and moisture content were made at three different depths using a nuclear gauge. Samples for geotechnical and environmental laboratory testing were collected at the same depths from some of the test pits to meet the total testing requirements set forth in the sampling and analyses plan prepared for the project. Additional measurements were made and/or samples collected as determined by the field engineer.

Gas Flux Measurements. The gas flux measurements were made on the existing cap material to evaluate the potential for landfill gas emissions and to assess whether a gas mitigation system was necessary.

Hollow-stem Auger Drilling. Five hollow-stem auger borings were made into the existing cap material on the P/S Landfill. These borings were completed to characterize the existing cap material to depths where excavations were necessary as part of the final cover construction. The borings extended to up to 27 ft (8.2 m) deep and geotechnical and environmental samples were collected for testing.

Ground Penetrating Radar (GPR). GPR was utilized to map the subsurface near the crests of the C/C and the M/S Landfills. This was done to locate waste containers (metal and plastic drums) buried close to the surface and encountered during initial excavations near the crest of the C/C Landfill.

Spectral Analyses of Surface Waves (SASW). A non-intrusive SASW investigation was conducted to evaluate the representative shear wave velocity profiles at the site required for seismic site response analyses. SASW measurements were made on lines established at thirteen locations over five landfills and at two locations over native soils. The locations of SASW lines are shown in Fig. 1. The SASW results provided indications regarding the shear wave velocities within the waste material and within the native material subgrade.

Cone Penetration Test (CPT) Soundings. CPTs were completed to evaluate the geotechnical properties of the existing cap material, waste material contained in the landfills, and existing toe buttress. A total of 43 CPTs were completed for four landfills. The CPT locations on the M/S, C/C, and Acids Landfills are shown in Fig. 1. The CPTs were conducted to a maximum depth of 130 ft (39.6 m) below ground surface. The CPT data were utilized to estimate undrained shear strength of the material, which was used in stability analyses.

The following equation [Robertson and Campanella, 1983a and b] was used to compute undrained shear strength, S_u, from measured CPT cone tip resistance:

$$S_u = (q_c - \sigma_o)/N_k \tag{1}$$

where, S_u is the undrained shear strength, q_c is the measured cone tip resistance, σ_o is the total overburden stress, and N_k is the cone factor.

In geotechnical practice the value of cone factor is typically estimated based on a knowledge of soil type and soil index properties, such as plasticity index. Because of the widespread use of CPT in recent years extensive data currently exists in literature, making proper selection of N_k values for different types of soils fairly routine.

However, the material encountered in the CPTs that extended through the landfill waste mass was not exclusively soils, but included hazardous waste materials, which possess widely varying physical characteristics and consistency. No reference was available in technical literature for estimating the appropriate value of N_k for such material.

The value of cone factor, N_k used in the present analyses was estimated based on two different approaches. First, on the basis of empirical interpretation of the CPT results using the Robertson [1990] correlation. t was recognized that the mechanical behavior of the waste materials is governed by its soil component and, consequently N_k was evaluated to correspond to the local clayey silt, silty clay, and clay.

Secondly, to narrow the previous estimate, the values of measured cone tip resistance were correlated with results of site-specific shear wave velocity measurements. This was done by employing two empirical correlations: one between shear wave velocity and shear strength of soft clay [Dickenson and Seed, 1994] and another between shear wave velocity and cone resistance [Mayne and Rix, 1995].

Based on the correlations with soil type, a value of cone factor, N_k of between 10 and 20 was believed to be appropriate. Based on the correlations with shear wave velocity, N_k of between 19 and 21 was estimated. In the actual analyses, a value of cone factor, N_k equal to 20 was utilized, as a conservative estimate.

The CPT data also provided information regarding the general nature of the subsurface material. The CPTs generally penetrated through different layers of material, including the existing cover, landfill waste mass, intermediate cover material between layers of waste, and in some cases the native subgrade of the landfill. As mentioned previously, the landfills were generally unlined, and were constructed with no engineered base liner, after excavations were made into native claystone subgrade.

Waste material was typically placed either in bulk or within containers. The CPTs which were extended within the landfills, encountered containerized waste materials. The CPT cone tip resistance indicated the penetration through the container as well as through the waste material within the container.

The cone tip resistance data from different CPTs were superimposed to identify the presence, if any, of continuous layers of relatively weak material within the landfill waste mass. This was of concern, since a continuous layer formed of material with relatively low shear strength could represent a potential failure plane through the landfill. After careful review no evidence of weak layers, either located between the cap and waste material, or located entirely within the waste material, was found. However, in spite of lack of direct evidence of any weak layer, separate stability analyses were completed with assumed values of "lower-bound" CPT data to simulate continuous layers of weak material in the waste mass.

DESIGN

Introduction

Only the design of the final cover system will be discussed in this paper. The final design also included the design and construction of a toe buttress system for the C/C Landfill, which will not be discussed in this paper.

Final Cover System

As per regulatory requirements, the final cover system on the hazardous waste landfills is required to conform to RCRA (Resource Conservation and Recovery Act) requirements. Thus, the final cover system configuration had to be either a cover system prescribed in RCRA guidance (prescriptive) or an alternative cover system (alternative) that either met or exceeded the performance of a prescriptive cover system.

The prescriptive cover system was not considered suitable at this site because of two reasons. First, there is no suitable local source for the low hydraulic conductivity barrier soil (hydraulic conductivity, $k = 10^{-7}$ cm/s) that is required in the RCRA-prescribed configuration. Secondly, the RCRA-prescribed configuration (see Fig. 2) includes an interface between the geomembrane layer and the barrier soil layer. Due to the high design seismic loading , it was deemed possible for a potential critical slip surface to develop below the liner along this interface. Because of this, it was necessary to evaluate the performance of alternative configurations.

In an early part of the design process, various alternative cover configurations were evaluated to identify the appropriate cover configuration for the landfills. These alternative configurations are shown in Fig. 2. The design criteria utilized to evaluate the performance of these alternative cover configurations included:

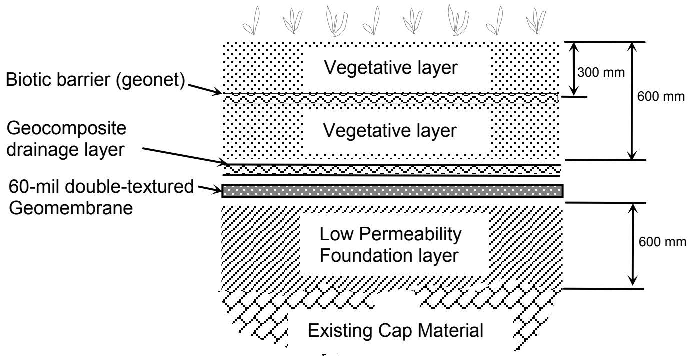
- Relative infiltration
- Static and seismic slope stability
- Settlement
- Drainage and erosion resistance
- Operations and maintenance
- Constructibility

The results of this part of design were used to compare between the performance of the different alternative cover configurations (Table 1).

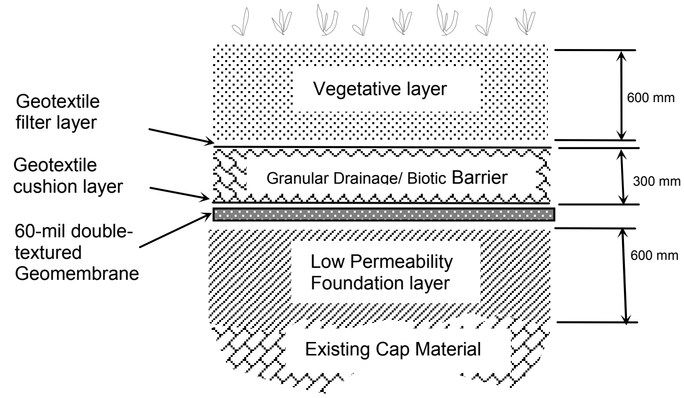
The cover system that was proposed for the P/S Landfill is shown in Alternative A in Fig. 2 and consisted of the following layers (from top to bottom):

- 2-ft (0.6-m) vegetative cover soil
- geonet biotic barrier layer, embedded 1 ft (0.3 m) within the vegetative cover layer
- geocomposite (geonet/geotextile/geonet) drainage layer
- geomembrane (60-mil or 1.5-mm, HDPE double-textured)
- 2-ft (0.6-m) of low hydraulic conductivity ($k \leq 10^{-6}$ cm/s) soil foundation layer

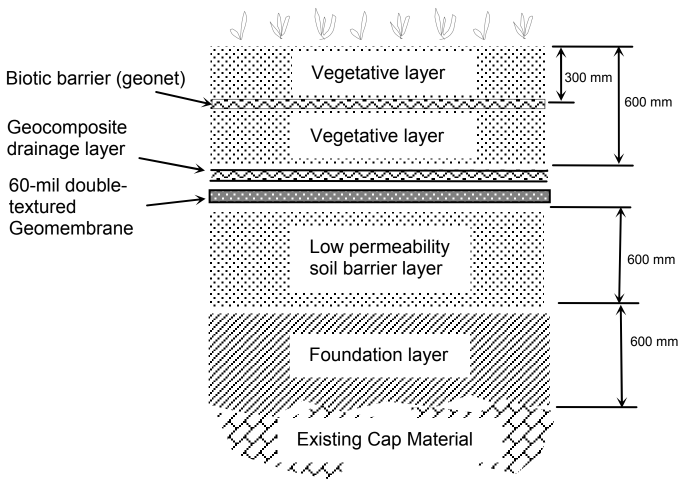
The low hydraulic conductivity foundation layer was composed of recompacted existing soil cover material, mixed with additional soil from on-site borrow source, thus eliminating the need for costly imported barrier layer soil.



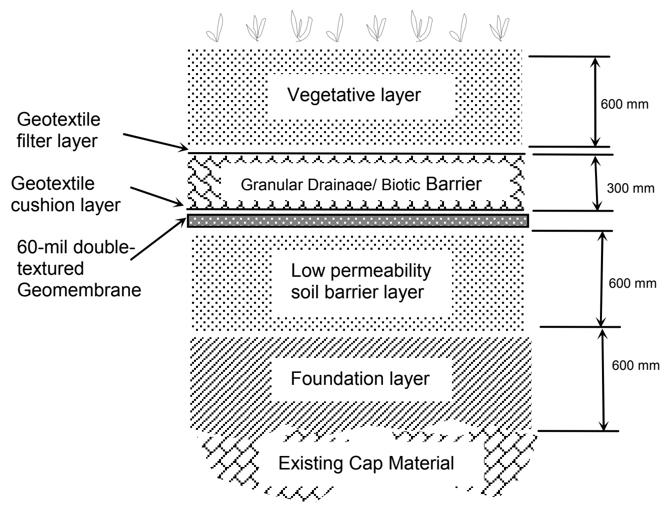
Alternative A
Composite Barrier Cap with Geomembrane and Gecomposite Drainage Layer
- Selected Final Cap Configuration for P/S Landfill



Alternative B
Composite Barrier Cap with Geomembrane and Granular Drainage Layer



Alternative C
Composite Barrier (RCRA) Cap with Gecomposite Drainage Layer



Alternative D
Composite Barrier (RCRA) Cap with Granular Drainage Layer

Note: Figures are not drawn to scale

Fig. 2. Alternative Cover Configurations for P/S Landfill

Table 1. Comparison of Cover Alternatives With Respect to Different Design Criteria

Alternative	A	B	C	D
Infiltration	Essentially Zero	Essentially Zero	Essentially Zero	Essentially Zero
Slope Stability	Suitable	Higher seismic deformations than Alternative A.	Suitable. Potential for critical interface between geomembrane and clay barrier layer.	Higher seismic deformations than Alternative A. Potential for critical interface between geomembrane and clay barrier layer.
Settlement	Lowest additional settlement	Increased additional settlement.	Increased additional settlement.	Highest additional settlement.
Drainage and Erosion Resistance	Suitable	Suitable	Suitable	Suitable
Operations and Maintenance Costs	Reasonable	Reasonable	Reasonable	Reasonable
Potential Damage in Design Earthquake (MCE)	Low. Movement above geomembrane.	Low, but greater than Alternative A. Movement above geomembrane.	Low to moderate. Potential for sliding of geomembrane.	Low to moderate, but greater than Alternative C. Potential for sliding of geomembrane.
Constructibility	Very good. No off-site borrow required.	Good. Requires off-site source of biotic barrier layer material.	Good. Requires source of low permeability soil.	Good. Requires source of low permeability soil and off-site source of biotic barrier layer material.
Adaptability to Future Closure Activities	Very adaptable.	Fairly adaptable.	Less adaptable, due to additional layers.	Less adaptable, due to additional layers.

During the construction of the P/S Landfill cover system, it was found that compacting the existing soil cover material and on-site borrow soil to obtain the necessary low hydraulic conductivity caused the construction process to be extremely slow and difficult. Because of the highly plastic nature of the on-site borrow soil, there was a relatively narrow "window" of dry density and moisture content at which it was possible to achieve the required hydraulic conductivity. Therefore, during the design of the final cover system for the other three landfills, a different final cover configuration was considered, such that the construction process was more efficient, while the cover will perform as well as or better than the previous configuration. This configuration is shown in Fig. 3 and consisted of the following layers (from top to bottom):

- 2-ft (0.6-m) vegetative cover soil
- geonet biotic barrier layer, embedded 1 ft (0.3-m) within the vegetative cover layer
- geocomposite (geonet/geotextile/geonet) drainage layer
- geomembrane (60-mil or 1.5-mm, HDPE double-textured)
- geotextile-based geosynthetic clay liner barrier layer
- 2-ft (0.6-m) of soil foundation layer

Final cover system, with the same configuration as above, was also installed over the interstitial areas between the landfills.

Relative Infiltration

The design storm event for which the cover was designed was a Probable Maximum Precipitation (PMP) event with rainfall measuring over 13.4 in. (340 mm) over a 24-hour period. The PMP was developed by statistical analyses of 47 years of historic rainfall data. This is an event which has a return period exceeding 10,000 years. For comparison, the average annual rainfall at the site is approximately 12.36 in. (314 mm). One regulatory requirement for this project was that, in addition to handling the large storm with suitable surface water drainage facilities, the landfill cover drainage layers must also handle storm flows without saturating the 2-ft (0.6-m) thick vegetative soil layer. This was also an important criterion required for stability of the final cover system, which were generally installed on slopes of 4 (horizontal) : 1 (vertical).

For the P/S Landfill, the infiltration through the final cover system was estimated in two stages using the Hydrologic Evaluation of Landfill Performance (HELP) computer program. A preliminary analysis was completed utilizing default rainfall data to compare the relative performance of the different alternatives presented in Fig. 2. The results of the preliminary HELP model analysis indicated that all four alternatives have essentially zero infiltration. The final phase of HELP model analysis for the P/S Landfill was completed only on Alternative A (selected configuration) and Alternative C (RCRA-prescribed configuration) for three precipitation cases, described below. For the M/S, C/C, and Acids Landfills only the final phase of HELP model analyses was completed with the selected alternative configuration (Fig. 3).

Three precipitation cases were modeled in HELP model analyses in the final phase:

1. Synthetically-generated 30 years of rainfall
2. Effect of irrigating the cover during the first two years after construction
3. A design rainfall corresponding to the PMP event, simulated under already saturated condition.

Details of these analyses and the design of the final cover system are provided in Dunn and De [2001 and 2002].

The final grades of the landfills were generally about 4 (horizontal) : 1 (vertical). The crest areas were designed to be graded to an average slope of approximately 4%, with a maximum slope length of 49 ft (15 m). Due to slope stability concerns, horizontal benches were constructed at vertical intervals not exceeding 30 ft (9 m). Most of the interstitial areas were at slopes between 10% and 20%.

HELP model analyses were completed on a range of combinations of slope inclinations and drainage lengths to evaluate the type of geocomposites required. The type of geocomposite was based on the head build-up over the geomembrane liner, with the maximum allowable head not to exceed the thickness of the geocomposite layer.

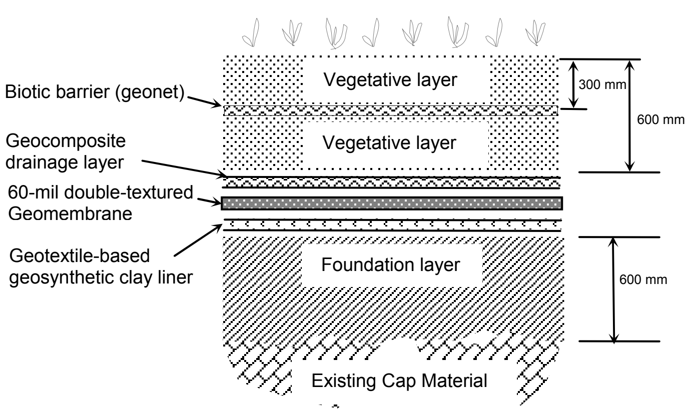


Fig. 3. Selected Final Cap Configuration for M/S, C/C, and Acids Landfills

Two types of geocomposites were identified for use. The first was a high transmissivity geocomposite, typically with a tri-planar geonet layer, having a minimum transmissivity of 5×10^{-4} m^2/s. This was specified for the relatively flat areas of the cover, especially where the drainage lengths were relatively long. The second was a conventional geocomposite, with a bi-planar geonet layer, having a minimum transmissivity of 1×10^{-4} m^2/s. This was specified for areas of the cover where the high transmissivity drainage layer was not required. The design of the geocomposite drainage layer is described in further details in Dunn and De [2002].

Static and Seismic Slope Stability of the Final Cover System

A focused testing program, consisting of interface direct shear and triaxial compression tests on the interfaces and the vegetative and foundation soils, was completed to allow identification of the critical interface and soil shear strengths, to be used in analyses. The test conditions modeled field conditions and the residual (large displacement) shear strength properties were used in analyses.

Preliminary stability analyses were completed using an infinite slope model and it showed that the estimated seismically-induced permanent displacements in the downslope direction were in excess of 12 in (300 mm), which was the maximum displacement acceptable to the regulatory reviewers. Therefore, the final cover grading was modified to limit the vertical distance between consecutive benches to be no more than 30 ft (9 m) and finite slope analyses were utilized. The most critical slope stability case was a shallow, non-circular failure surface at the critical interface in the cover system. Site-specific seismic site response and deformation analyses were completed to demonstrate that the estimated seismically-induced permanent displacements of the final cover system are below 12 in. (300 mm).

Settlement

Design considerations for the settlement analyses were the following:

- Cap materials and their relative ability to withstand strains due to total and differential settlements and subsidence
- The relative weight and thickness of the final cover and the resulting incremental load that will generate additional settlement
- Selection of cover grades to reduce potential for disruption in surface water drainage

Because of the general lack of geotechnical data on settlement characteristics of waste materials, settlement analyses were limited to parametric evaluations, using data available in technical literature. Based on the estimated effects of calculated ranges of settlements and subsidence, all cover configurations considered in the design process were found to indicate satisfactory performance. Alternative A required only 2 ft (0.6 m) of additional fill and resulted in the lowest settlement.

CONSTRUCTION

Design was completed in two separate phases, such that the design of the final cap system for the M/S, C/C, and Acids Landfills was completed during and after the construction of the P/S Landfill. This allowed for lessons learned from the construction phase of the P/S Landfill closure to be incorporated into the design of the other three.

The key lesson learned and implemented pertained to the construction of the low-hydraulic conductivity foundation/barrier layer utilizing existing cap material, mixed with on-site borrow material. Because of the nature of this soil (as discussed before) it was found to be extremely difficult to achieve the required hydraulic conductivity during the construction of the P/S Landfill cover system. As a result, the low-hydraulic conductivity requirement for this soil layer was eliminated in the design of the cover system for the other three landfills and a conventional foundation layer was constructed. In lieu of the soil barrier layer, a geosynthetic clay liner was installed directly above the foundation layer. Interface direct shear tests were completed to verify that the most critical interface was still between the geomembrane and the geocomposite and was thus located above the liner.

CONCLUSIONS

This paper describes the site characterization, design, and construction of the final cover system for four hazardous waste landfills at a major Superfund site in the Central Coast region of California.
A major challenge in the site characterization process was the lack of guidance available in technical literature for geotechnical characterization of hazardous waste. This was overcome through the use of extensive field and laboratory testing and through cross-correlations between data obtained in different investigations (e.g., between CPT and SASW data).

The design parameters in this project were relatively stringent, in the form of a design seismic loading that corresponds to a bedrock peak horizontal ground acceleration of 0.86 g and a design precipitation event of 340 mm in a 24-hour period. These parameters were satisfied through appropriate design elements. The criterion for seismic stability of the final cover system was satisfied by ensuring that horizontal benches at relatively short vertical intervals (30 ft or 9 m) were included in the design and that the critical slip surface was above the geomembrane liner. Finally, site-specific seismic response analyses and deformation analyses were completed to demonstrate that seismically-induced permanent displacements are within acceptable limits.

The relatively high design precipitation was handled by utilizing a high transmissivity geocomposite material in areas where relatively flat slopes were located over larger drainage lengths. This ensured that the maximum head over the liner would not exceed the thickness of the geocomposite layer.

Improvements in the design were accomplished when the construction of the final cover system of one of the landfills preceded the design of the other three. Thus, the difficulty of achieving the required hydraulic conductivity value with the available soil was overcome by introducing an additional geosynthetic clay liner layer.

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